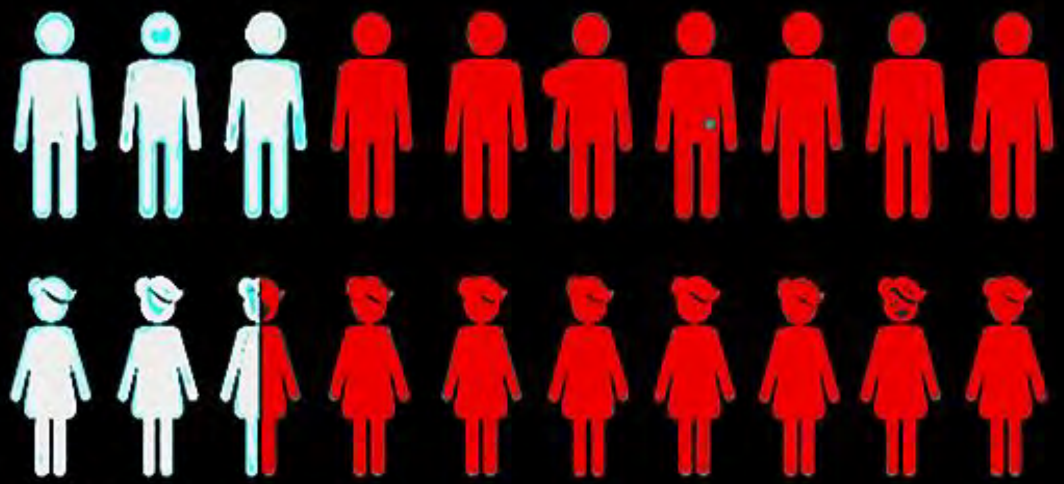
EU Cities and Heat Extremes

On the magnitude of Urban Climate Change, Its impact on Energy, Health, Productivity, Vulnerable Population, Economy and Environmental Quality. Heat Mitigation and Adaptation Potential and Proposals to Counterbalance Urban Heat

M. Santamouris, UNSW, Sydney, Australia



13,000 OVERHEATED CITIES

1.7 BILLION PEOPLE UNDER SEVERE OVERHEATING

THREE TIMES MORE OVERHEATING HOURS SINCE 1980

118 BILLION OVERHEATING MAN HOURS

C. Tuholske *et al.*, "Global urban population exposure to extreme heat," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 118, no. 41, pp. 1–9, 2021, doi: 10.1073/pnas.2024792118.

Rises the cooling energy consumption in cities ,

Decreases the efficiency of power plants

Rises the peak electricity demand

Increases the emission of pollutants of the power plants

Increases the concentration of ozone

Intensifies heat related mortality and morbidity

Causes serious Mental Health Problems

Lowers the productivity of population

Increases the Risk of Accidents

Affects the survivability of vulnerable population

Increases the Cooling Energy Consumption

Urban overheating is inducing an additional energy penalty at the city scale close to 0.74 kWh/m2 /°C, while the average energy penalty per person, is close to 237 (± 130) kWh/p

Increases the Peak Electricity Demand

The peak electricity rise per degree of temperature increase varies between 0.45% and 4.6%, corresponding to an additional electricity penalty close to 21Watts (± 10.4) per degree of temperature increase and per person

Decreases the Efficiency of Power Plants

A 1 °C rise of the ambient temperature reduces the power output of thermal and nuclear power stations by 0.6%

M. Santamouris, "Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change," *Energy Build.*, , 2020,

Urban overheating obliges utilities to operate power plants for an extended period to satisfy the peak electricity demand

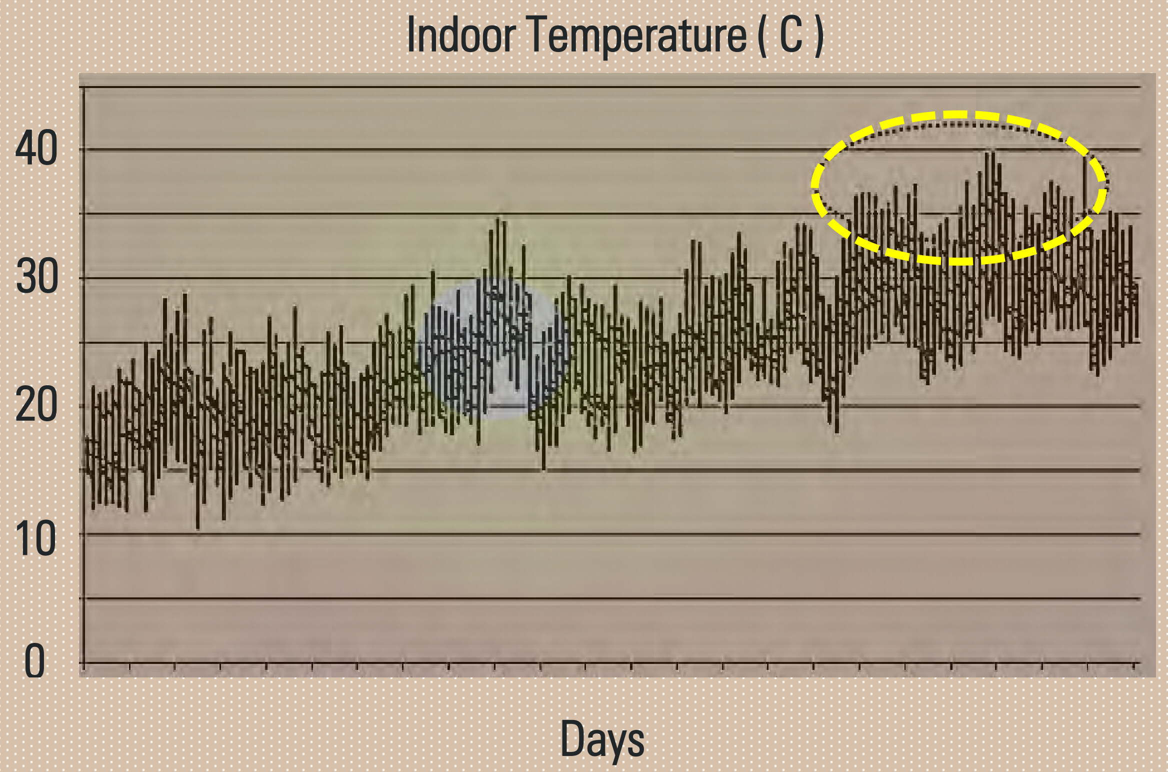
Increased operation of thermal power plants significantly rises the emissions of pollutants and increases the concentration of secondary pollutants like the ground level ozone.

Each degree of temperature rise in the Eastern United States during the period between 2007-2012, resulted in a rise by:

3.35%/°C ±0.50%/°C of the SO_2 emissions,
3.32%/°C ±0.36%/ °C rise in CO_2 emissions, and a
3.60%/°C ±0.49%/°C increase in NO_X emissions.

It is predicted that in 2050 the corresponding NOx emissions may increase by 16%, and the SO_2 emissions by 18%.

M. Santamouris, "Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change," *Energy Build.*, vol. 207, 2020



Rich experimental data exist in the developed countries regarding the indoor environmental quality of low-income houses during the period of high ambient temperatures.

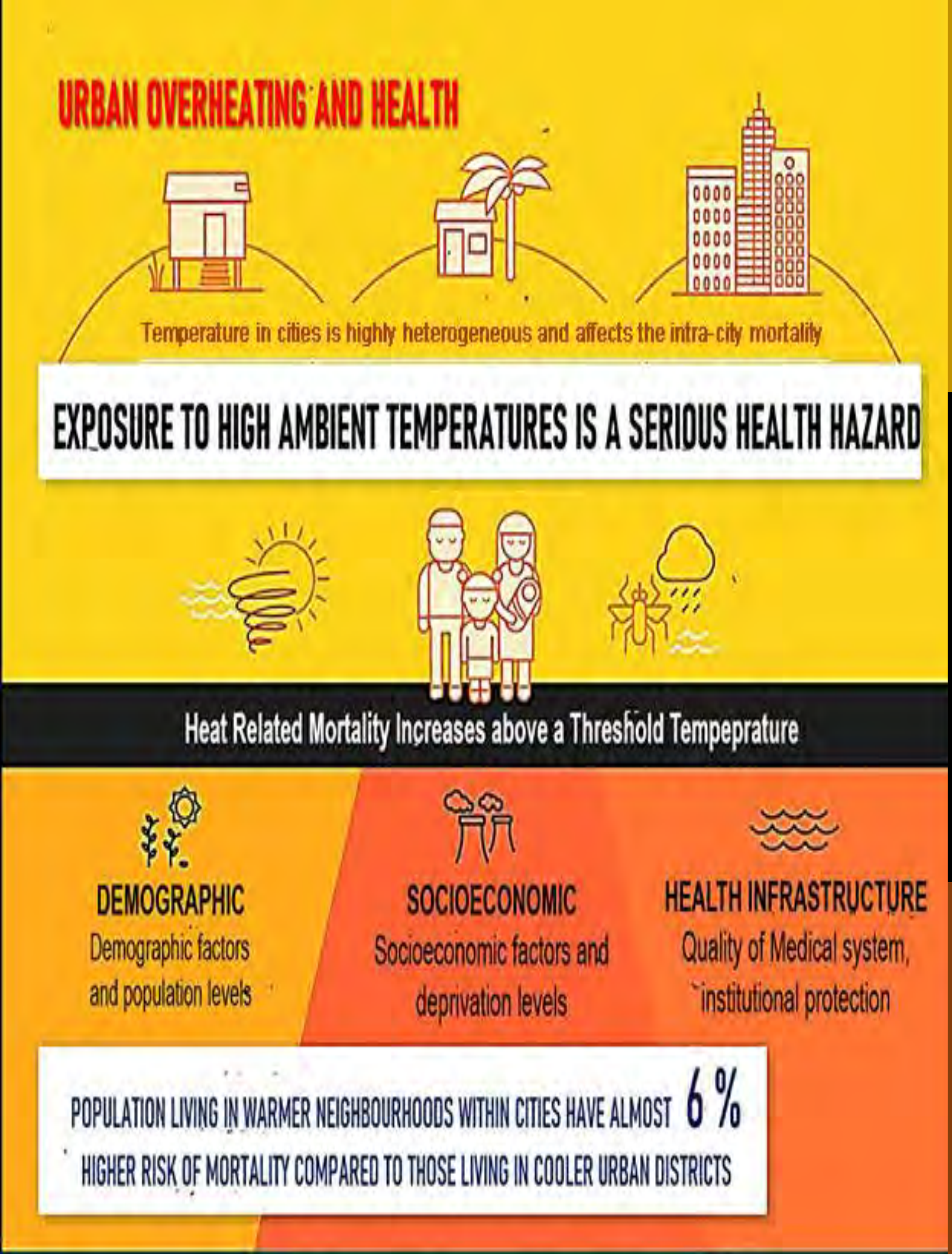
Continuous measurements of the indoor ambient temperature and CO2 concentration, are performed in 110 low-income buildings in Western Sydney and rural NSW, for about 12 months.

It is found that during the summer period and not during a heat wave, indoor temperature was close to 40 C.

In parallel, the indoor concentration of CO2 was up to 4 times higher than the threshold acceptable levels.

During the winter period, indoor temperature was as low as 5- 7 C.

Shamila Haddad, Riccardo Paolini, Afroditi Synnefa, Lilian De Torres, Deo Prasad, Mattheos Santamouris : Integrated assessment of the extreme climatic conditions, thermal performance, vulnerability, and well-being in low-income housing in the subtropical climate of Australia, Energy and Buildings, 272, 112349, 2022

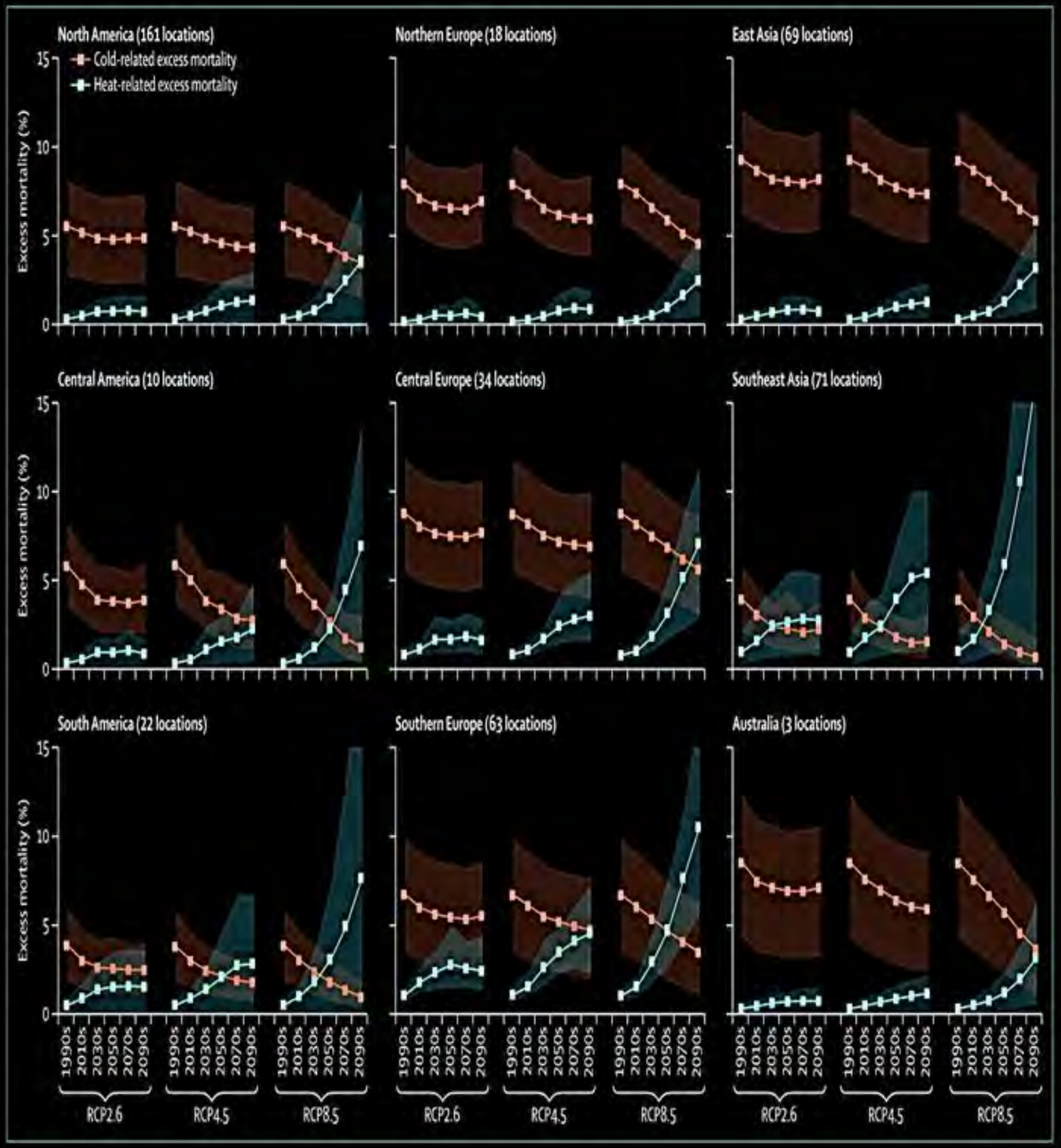


When exposed to temperature beyond a certain threshold, the human thermoregulation system cannot offset the impact of extreme heat resulting in increased global mortality and morbidity

Heat related morbidity and mortality caused by the local climate change, is highly alarming, and it seems to be one of the current and future peak scientific topics .

Elderly is the most vulnerable population group
Those with preexisting health problems like respiratory, cardiovascular, or mental health problems
Those using medication that affects thermoregulation, and
Those 'lacking in economic assets and access to public support systems, with diminished physical or cognitive capacities to respond to warnings and missing strong and enduring social support systems like social isolated people, and those living in hazardous places'

According to the existing epidemiological records almost 59,114 people passed away between 2000 and 2007 during 52 extreme heat events around the world



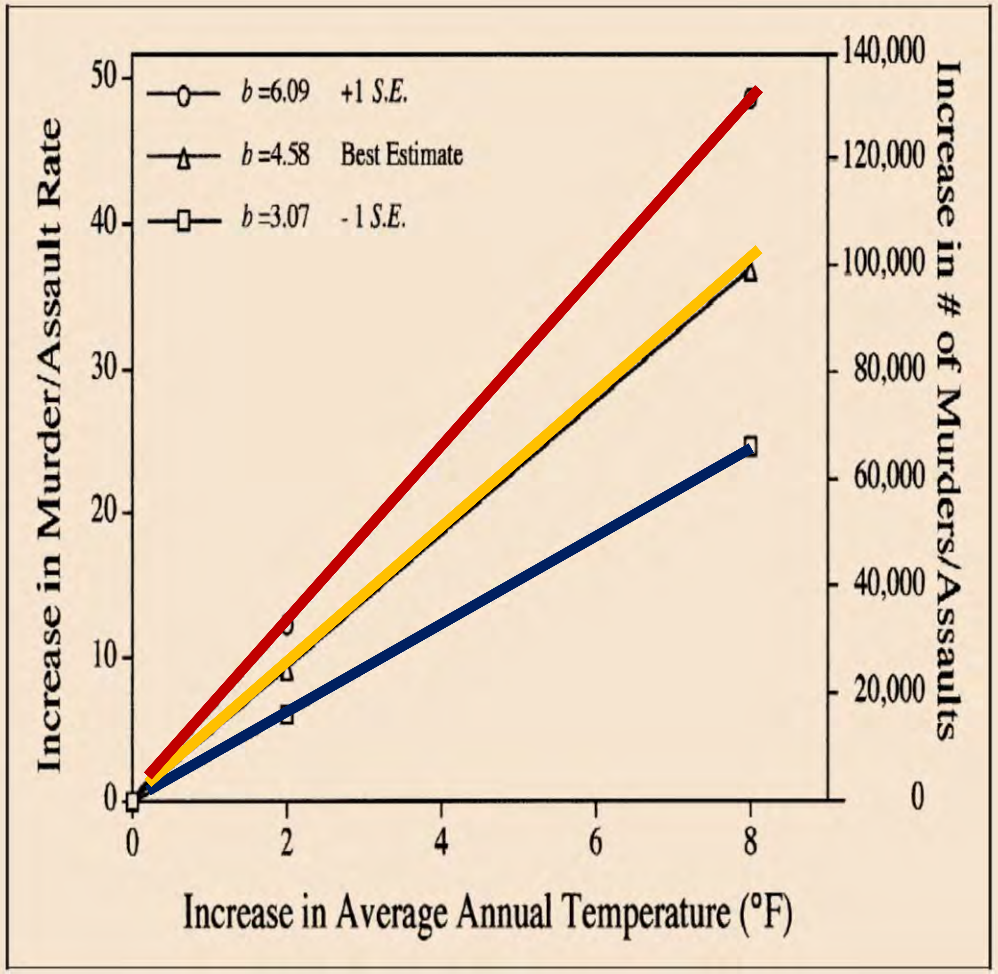
Lancet has published an extended epidemiological investigation on the potential health effects of higher ambient temperatures under various climate change scenarios, socioeconomic and demographic conditions , public health status and levels of economic development. services.

‘The study indicates that, in high-emission scenarios, most regions are projected to experience a steep rise in heat-related mortality that will not be equaled by a reduction in cold-related deaths, resulting in a substantial positive net increase in mortality.

However, the potential impact varies across areas, and populations living in warmer and potentially poorer regions are expected to sustain an increased burden.

Furthermore, the increase in temperature-related excess mortality would be substantially reduced in scenarios involving mitigation strategies to limit greenhouse gas emissions and further warming of the planet, and stricter mitigation approaches are associated with larger benefits’.

www.thelancet.com/planetary-health Vol 1 December 2017



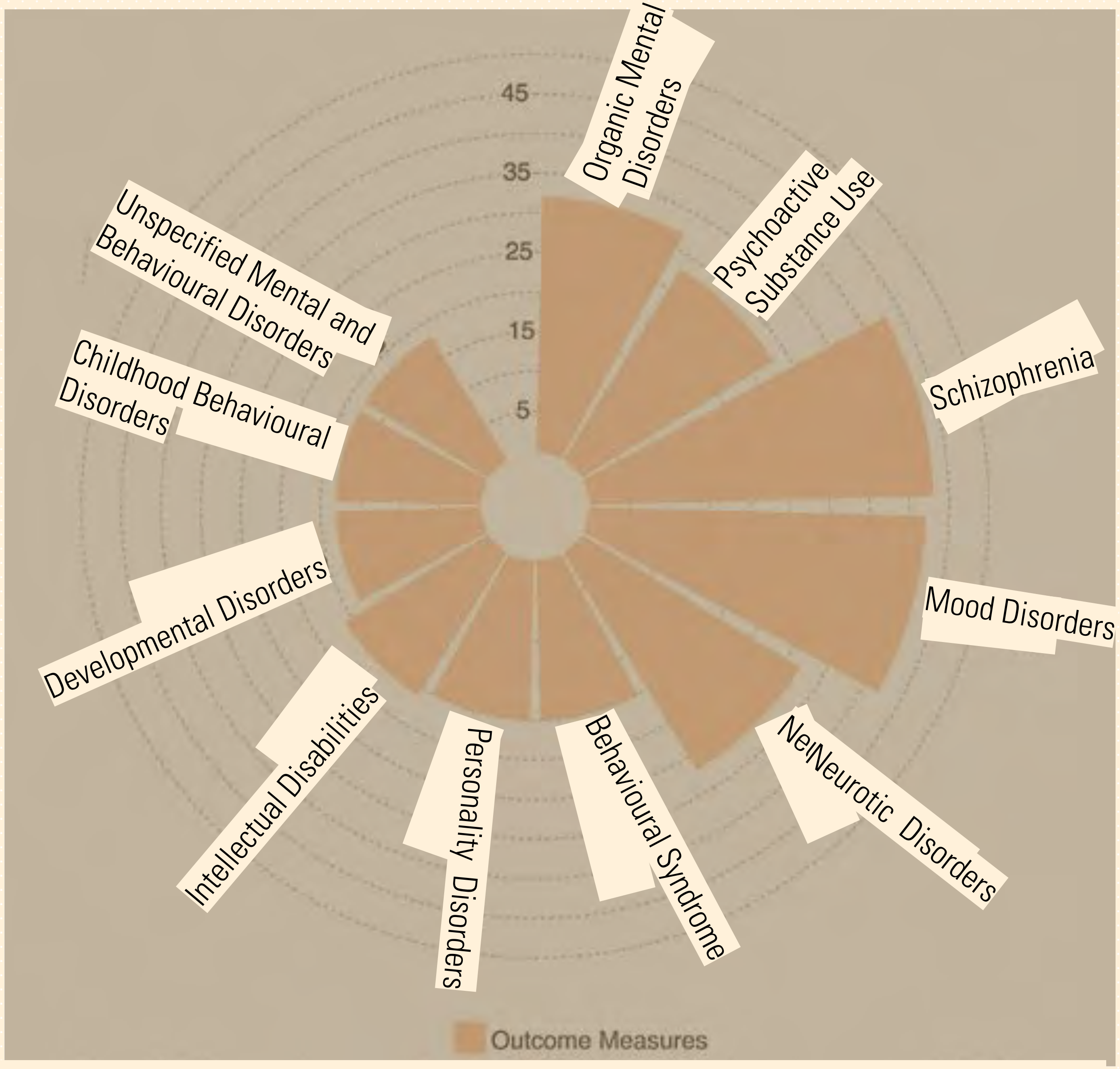
Urban Overheating has a serious adverse impact on wellbeing and threats mental health.

Mental health impacts are expected to arise from climate-related economic and social losses and anxiety and distress associated with overheating.

It is found that there is a statistically significant correlation between the increase of the ambient temperature and the corresponding increase of murder and assault rate.

Similar statistics have been observed for numerous cities around the world during period of extreme temperature.

Heat and Violence. Article *in* Current Directions in Psychological Science · February 2001 DOI: 10.1111/1467-8721.00109



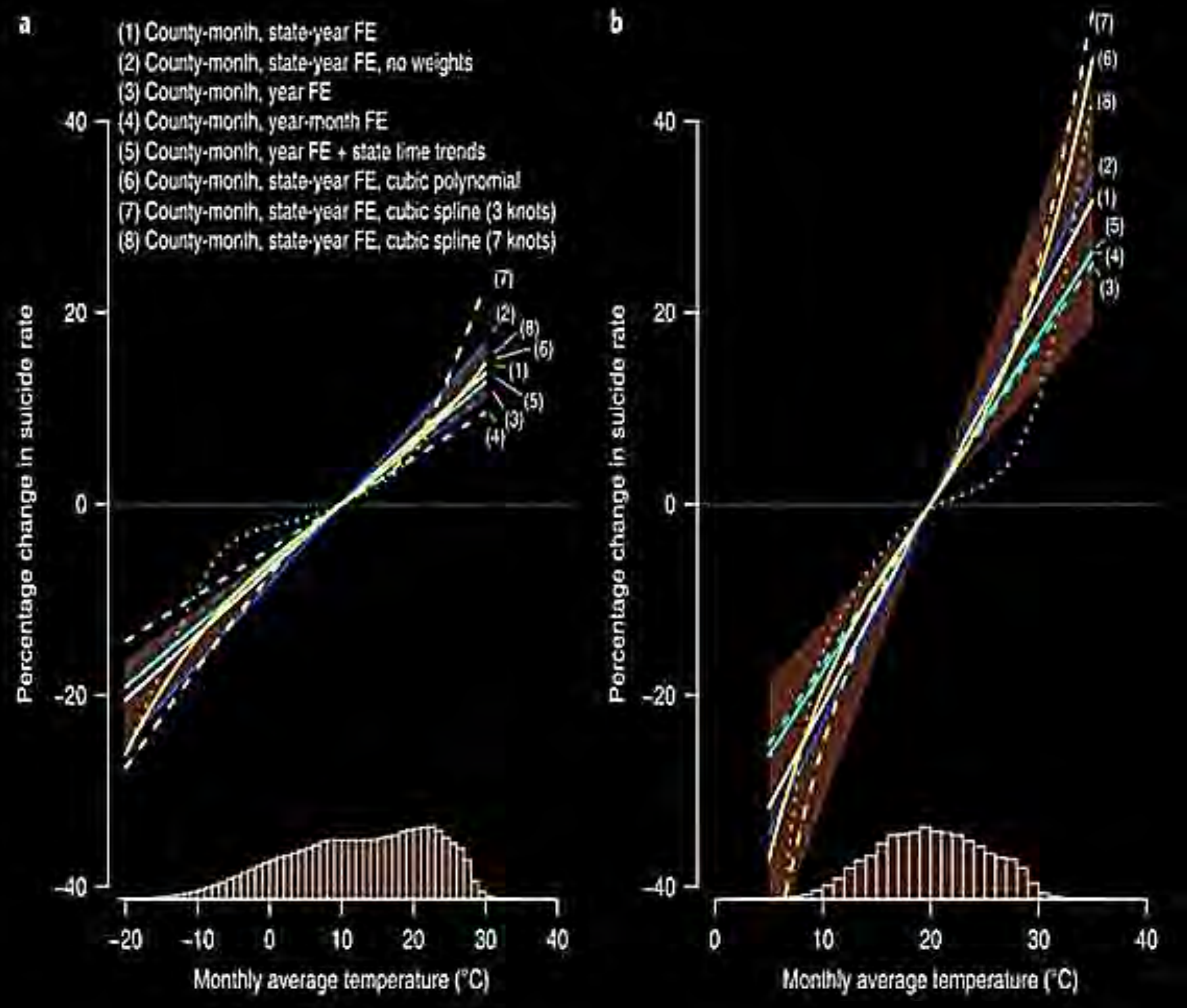
Hea

Numerous studies have revealed critical associations between temperature extremes, and mental illness
Three types of climate-related events (acute, subacute, and long-lasting changes) on mental health are identified. Extreme heat events that occur in summer could pose a serious risk to human mental conditions.

Meta-analysis showed that heatwaves and extreme high temperatures were associated with higher risk of schizophrenia, mood disorders, neurotic disorders.

A strong association between increases apparent temperature and elevated risk of Mental Behavioral Disorders.
A 99th percentile high temperature was associated with increased schizophrenia risk

D.Li et al: Climatic and Meteorological Exposure and Mental and Behavioural Health. A systematic Review and Metanalysis. Science of the Total Environment, 2023.

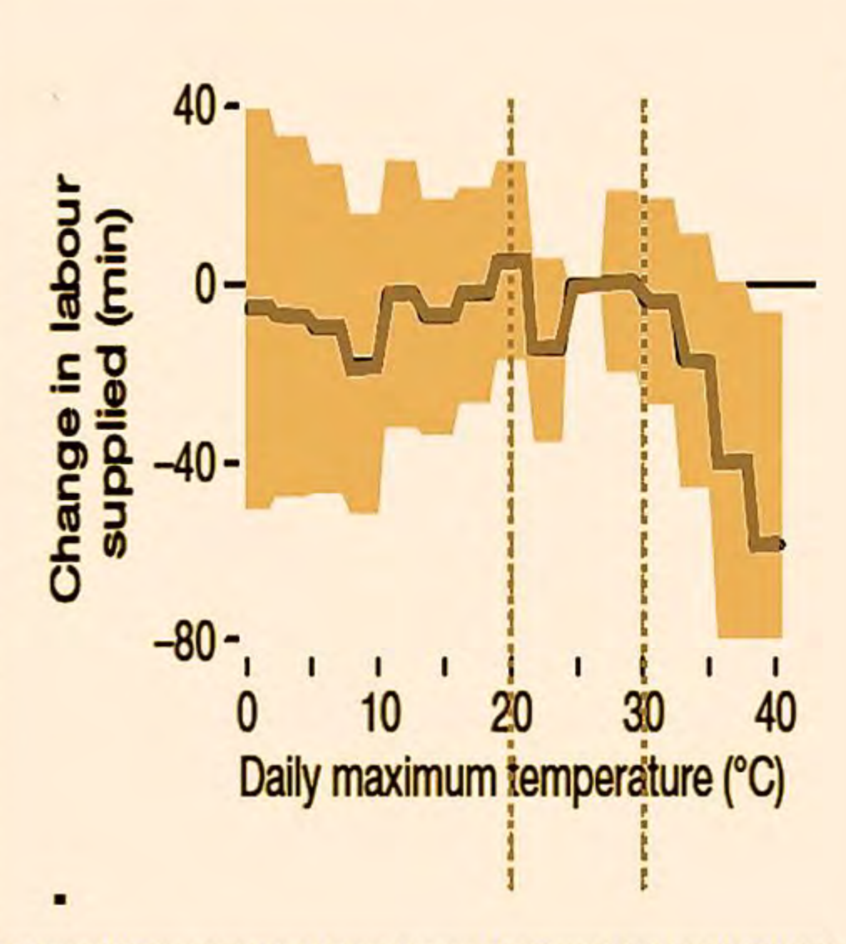


Using comprehensive data from multiple decades for both the United States and Mexico, it is found that suicide rates rise 0.7% in US counties and 2.1% in Mexican municipalities for a 1 °C increase in monthly average temperature.

This effect is similar in hotter versus cooler regions and has not diminished over time, indicating limited historical adaptation.

In contrast to all-cause mortality, suicide increases at hot temperatures and decreases at cold temperatures; also unlike all-cause mortality, the effect of temperature on suicide has not decreased over time and does not appear to decrease with rising income or the adoption of air conditioning.

Burke et al : High Temperatures Increase Suicide Rates in the USA and Mexico, Nature Climatic Change 2018



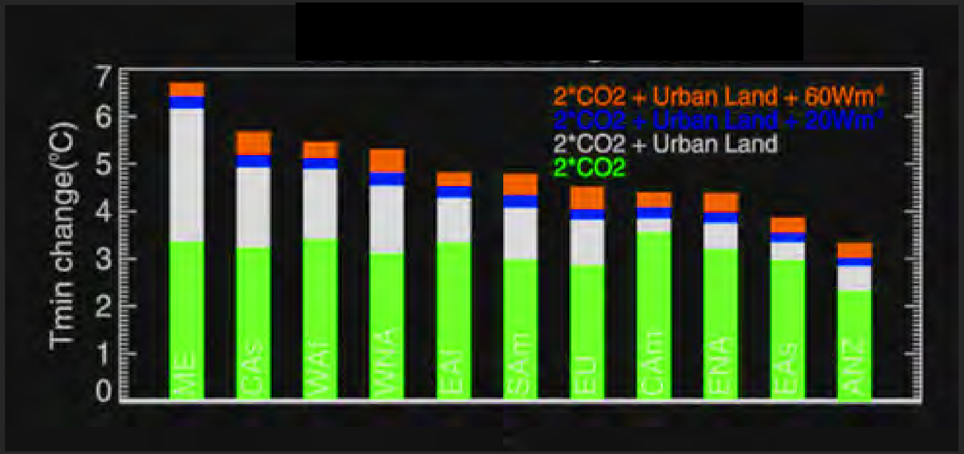
Recent research found that labour supply and human productivity may decrease up to 60% when ambient temperature exceeds 30-35 C

Recent research found that labour supply and human productivity may decrease up to 60% when ambient temperature exceeds 30-35 C

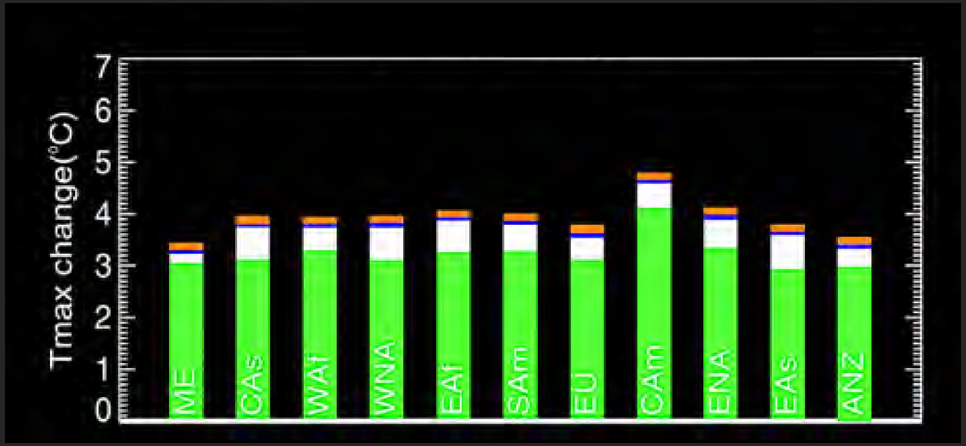
Recent research found that labour supply and human productivity may decrease up to 60% when ambient temperature exceeds 30-35 C

Graff Zivin, J. & Neidell, M. Temperature and the allocation of time: Implications for climate change. J. Labor Econ. 13, 1–26 (2014).

Potential Increase of Min Nighttime Temperature (C)



Potential Increase of Max Daytime Temperature (C)



Simulated Increase of the Urban Temperature and UHI caused by the combined impact of greenhouse gas and urban expansion forcing, (RCP 8.5)

Increase in the Surrounding Rural zone (2 x CO2)

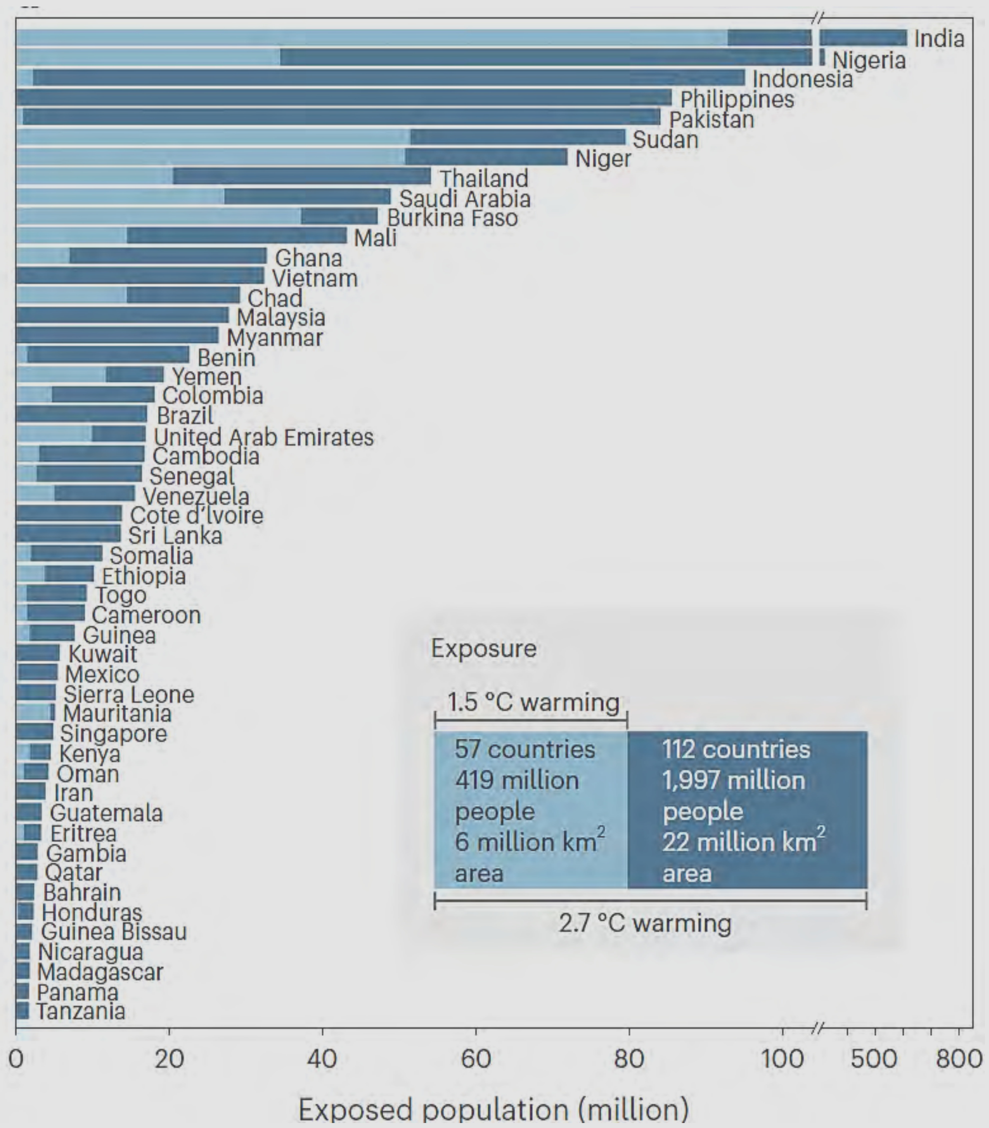
Increase in the City (2 x CO2)

Increase in the City (2 x CO2)+ 20 w/m2 anthropogenic heat

Increase in the City (2 x CO2)+ 60 w/m2 anthropogenic heat

Middle East (ME), Central Asia (CAs), West Africa (WAf)
West North America (WNA), East Africa (EAf), South America (SAm),
Europe (EU), Central America (CAm), East North America (ENA),
Australia and New Zealand (ANZ)

Climate change in cities due to global warming and urban effects. Mark P. McCarthy, Martin J. Best, and Richard A. Betts, GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L09705



The 'human climate niche' is defined as the historically highly conserved distribution of relative human population density with respect to mean annual temperature.

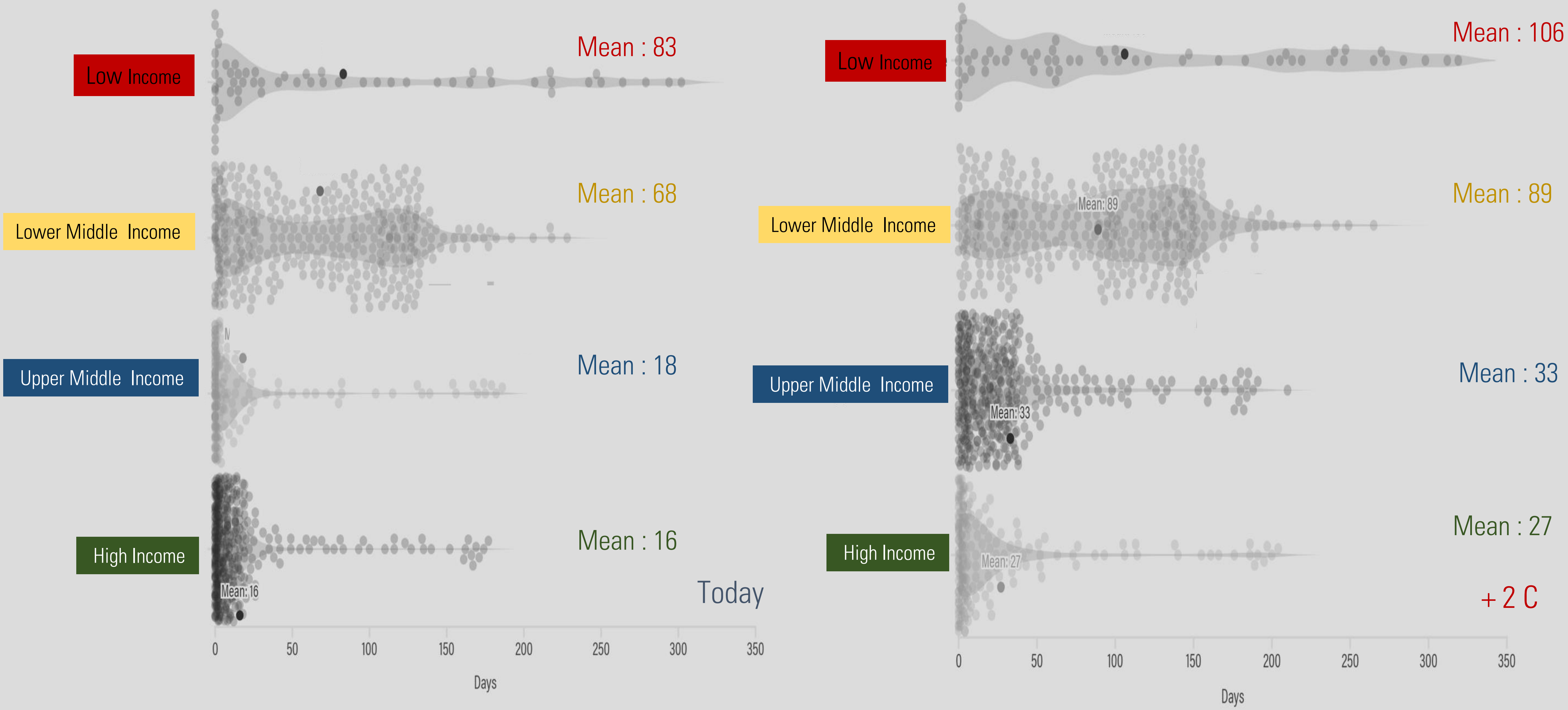
Climate change has already put ~9% of people (>600 million) outside this niche

Country-level exposure to unprecedented heat (MAT ≥29 °C) at 2.7 °C and 1.5 °C global warming in a world of 9.5 billion people (around 2070 under SSP2).

Population exposed for the top 50 countries ranked under 2.7 °C global warming (dark blue) with exposure at 1.5 °C global warming overlaid (pale blue).

Timothy M. Lenton , Chi Xu, Jesse F. Abrams, Ashish Ghadiali, Sina Loriani, Boris Sakschewski, Caroline Zimm, Kristie L. Ebi, Robert R. Dunn, Jens-Christian Svenning & Marten Scheffer: Quantifying the human cost of global warming, Nature Sustainability, 2023

Days per Year that Max Temperature Exceeds 35 C by City



Source: WRI analysis from IPCC Interactive Atlas, Bias Adjusted TX35 from CMIP6.

WORLD RESOURCES INSTITUTE

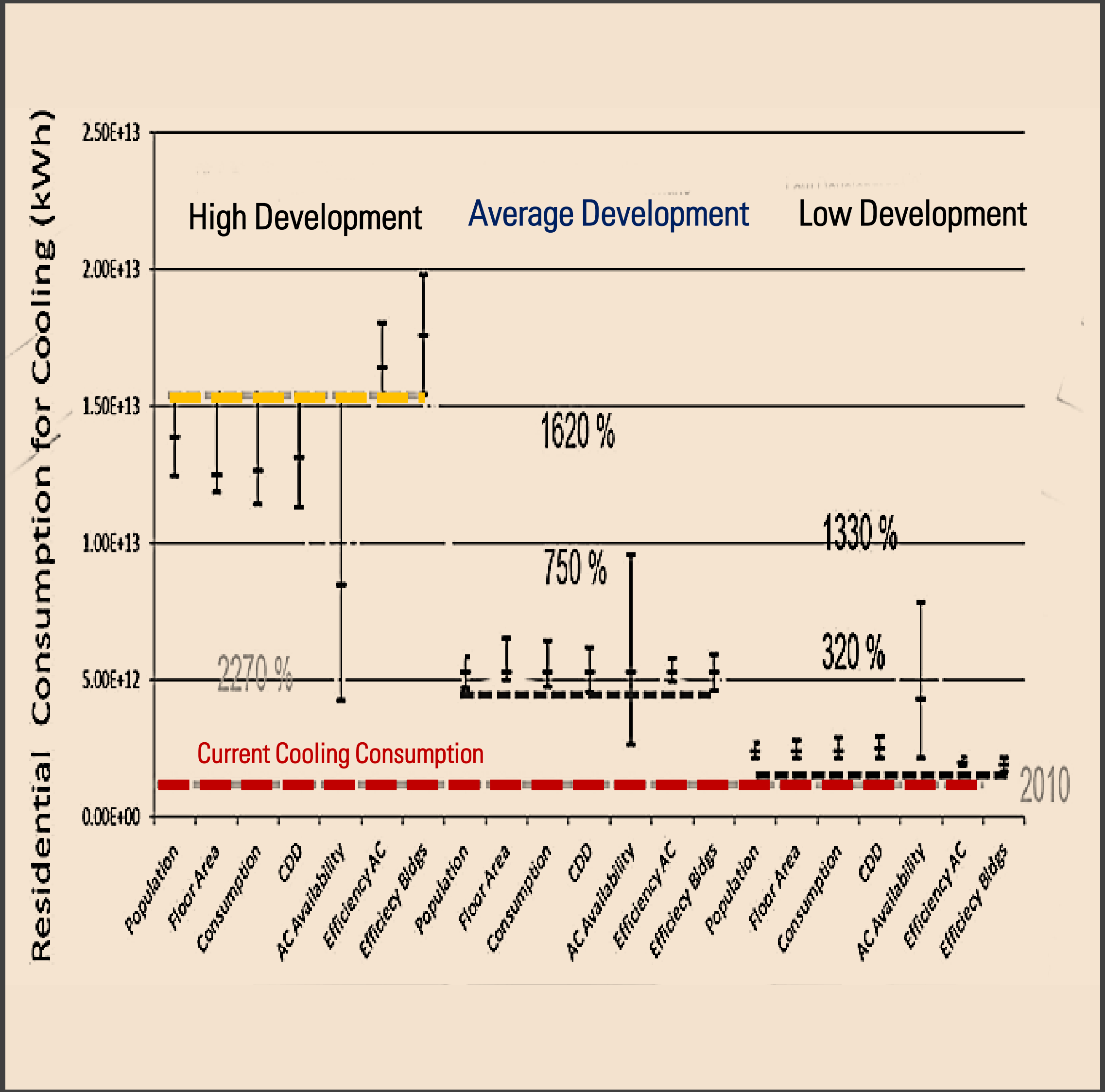
There currently is a shortfall of about 330 million homes in the world, and is expected to increase up to 440 million by 2025.

By 2030 the additional housing needs will grow by more than 77 billion square meters of floor space, equivalent or greater than the actual area of China

More than **225 billion square meters** of floor area will be built in emerging economies and mainly in India, Indonesia and Brazil

We add a total floor area equal to the city of Paris per week.

M. Santamouris : Minimizing Energy Consumption, Energy Poverty and Global and Local Climate Change in the Built Environment: Innovating to Zero, Causalities and Impacts in a Zero Concept World, Elsevier, 2019



Cooling Energy Consumption of Buildings by 2050

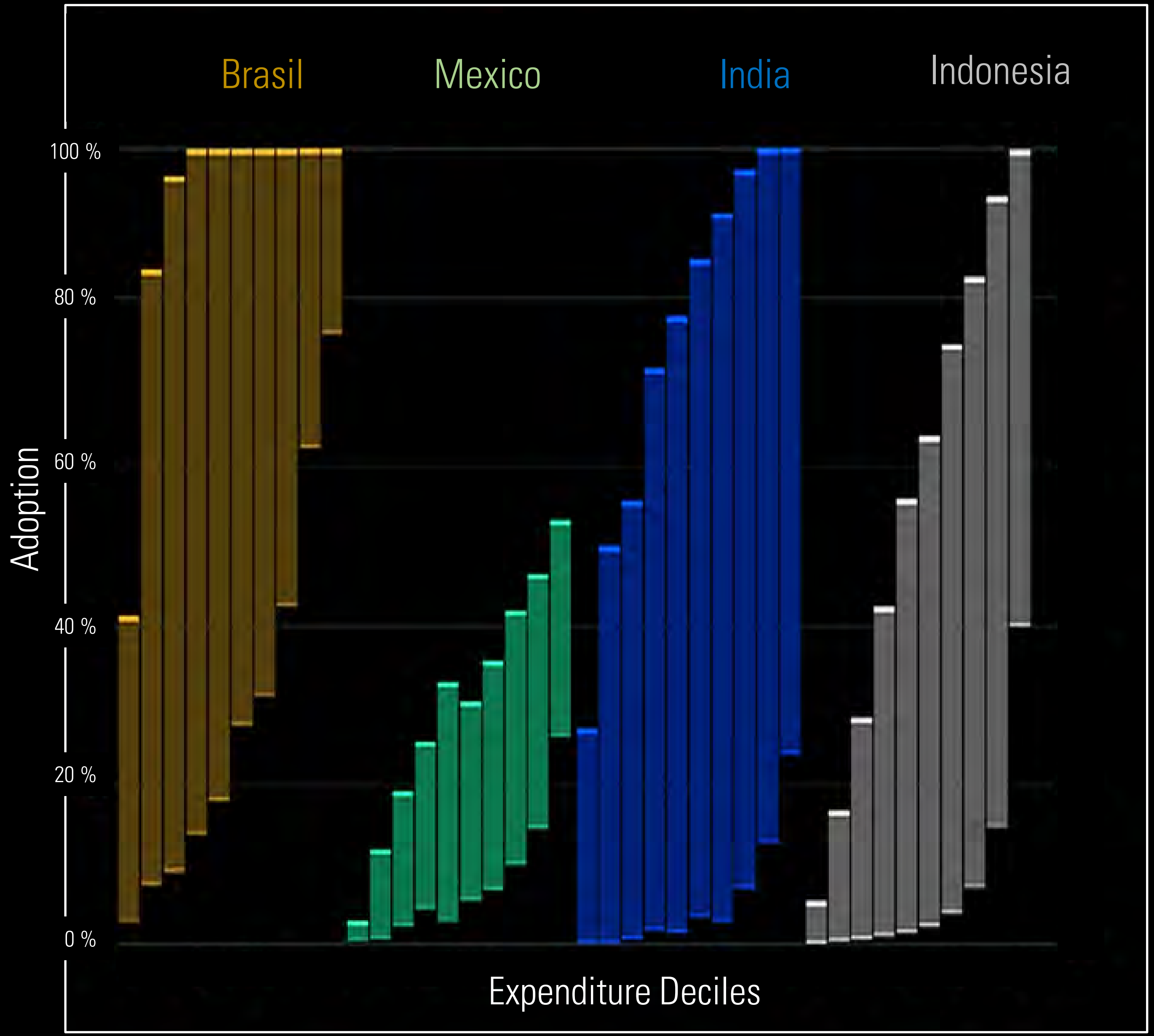
Data shows that extreme heat drives higher air conditioner demand, with sustained average daily temperatures of 30 C typically boosting weekly sales by around 16 %.

Cooling energy consumption in buildings may rise by 200% and up to 2,000% by 2050, depending on the evolution of the main economic and climatic drivers.

.

The total cost of urban overheating is estimated between 500 – 700 billion US $ per year, and may increase up to 1.3 Trillion US $ by 2050

M. Santamouris : Cooling of Buildings. Past, Present and Future, Energy and Buildings, 128 (2016)

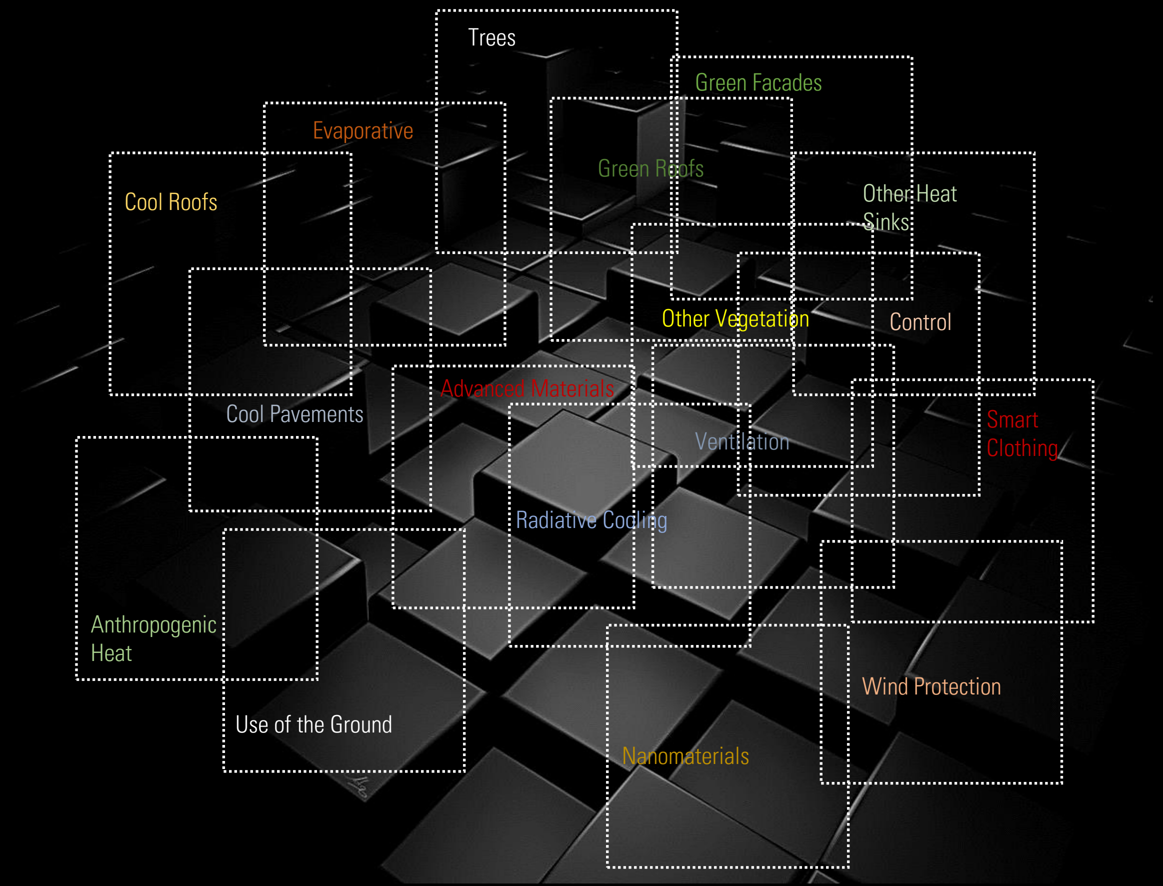


The Current and Future Penetration of A/C in Emerging Economies per Income Group demonstrates that low income population will not have access to air conditioning.

By 2040, a nonnegligible fraction of the population will be left behind.

On 2040, between 64 and 100 million households out of the total number of households living in the four countries considered in the latest waves of 343 million will face an adaptation cooling deficit

NATURE COMMUNICATIONS | (2021) 12:6460 | https://doi.org/10.1038/s41467-021-26592-2 | www.nature.com/naturecommunications



To counterbalance the impact of urban overheating, heat mitigation techniques are developed, and successfully implemented.

Mitigation technologies involve the use of advanced urban materials like:

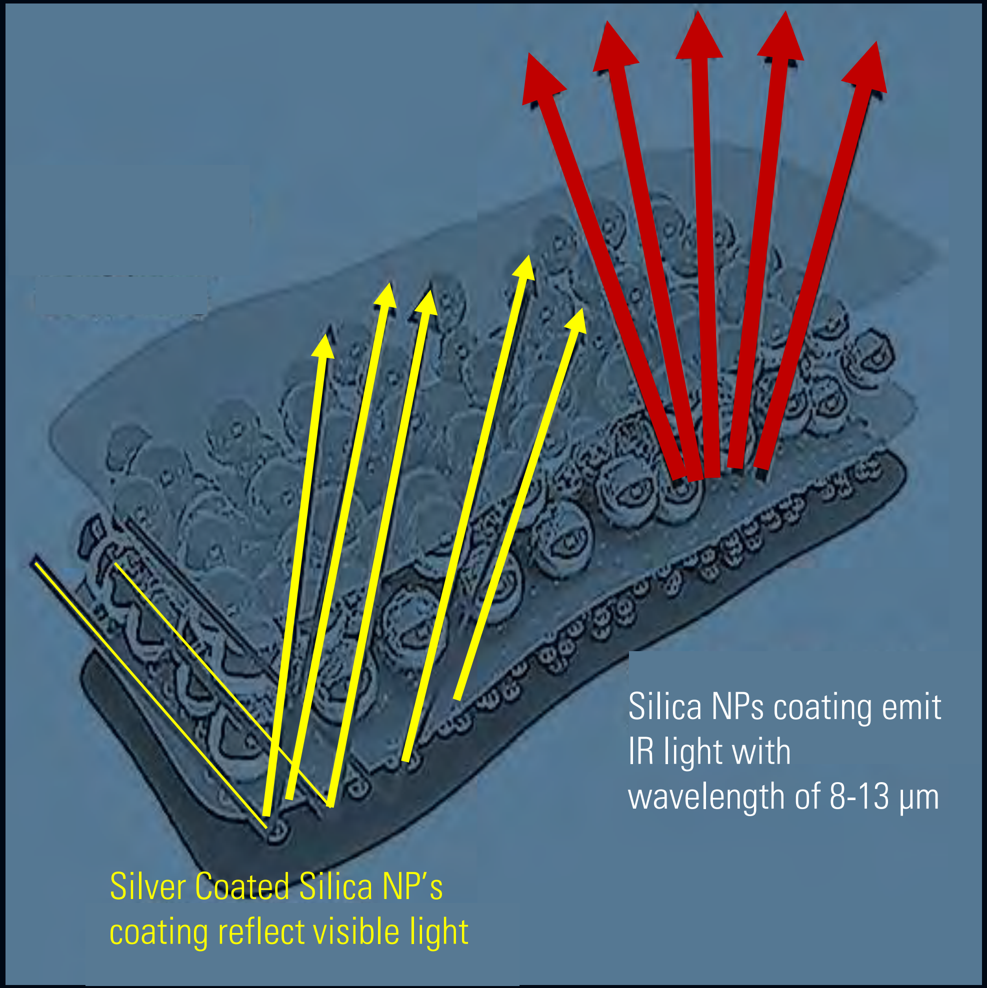
Reflective, thermochromic, photonic, plasmonic and fluorescent materials,

The increase of the urban green infrastructure,

The use of evaporative systems,

Dissipation of the excess urban heat to low temperature heat sinks,

Or, a combination of the previous technologies.



Passive Radiative Coolers, or Super Cool Materials, present a very high solar absorptance combined with a high emissivity in the atmospheric window, 7-13 μm.

The recent development of

Super Cool Materials

like the photonic and fluorescent materials, permits the decrease of the surface temperature of buildings and urban structures up to 15 C below the ambient temperature under the summer sun

The implementation of SCM in cities can reduce the peak ambient temperature up to 4-5 C and provide very significant energy and health benefits.

The developed samples of the Super Cool Materials have been extensively tested outdoors in Alice Springs, Australia, under desert conditions, to characterize their cooling performance.

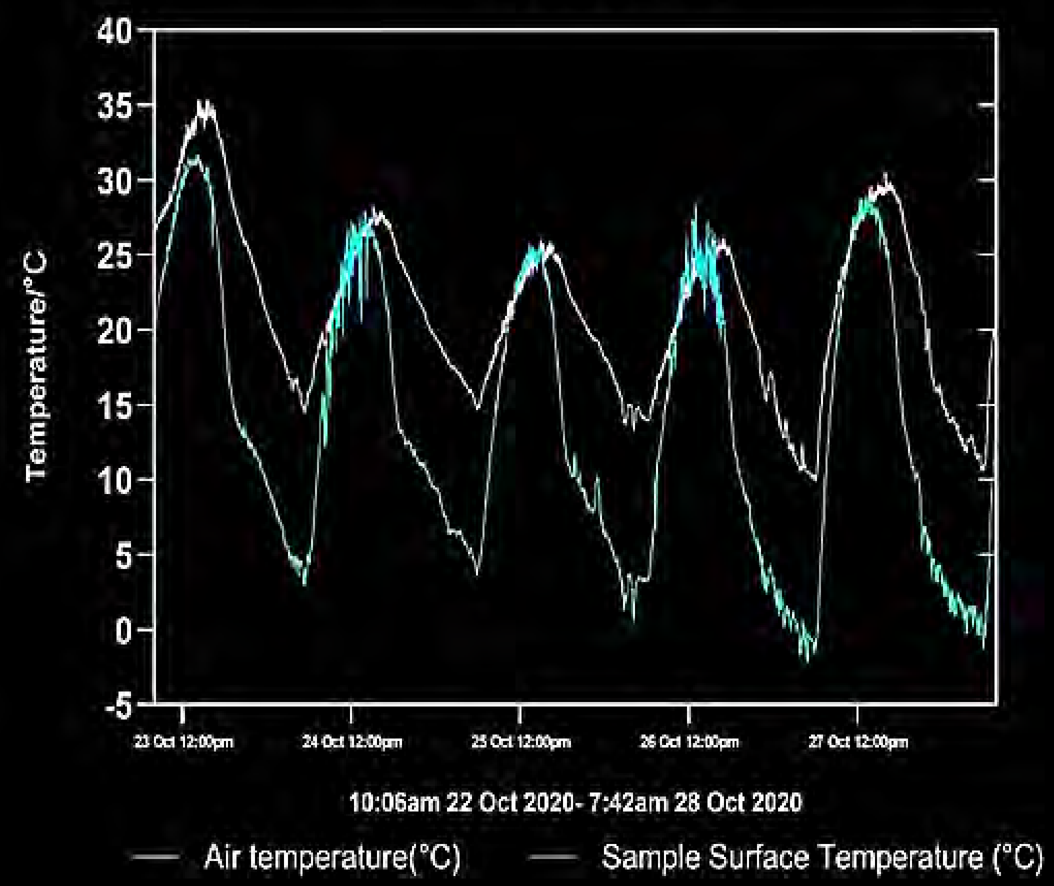
Six Samples with Different Characteristics have been designed.

The microstructure of the samples was analyzed by field emission SEM (FESEM; FEI Nova NanoSEM 230, 3 kV) and their element composition was studied by EDS - Energy Dispersive Spectrometry).

Desert climatic conditions permit testing under high day time ambient temperature and solar radiation intensity.

However, the desert atmosphere contains a high concentration of SiO2 that is highly absorbing in the atmospheric window, thus decreasing the cooling performance of the materials.

Silica TPX Sample + ESR + Silver Pet Film



Testing has been carried out during five consecutive days.

Day time ambient temperature varied between 25 to 35 C

The peak solar Radiation intensity was between 800 to 100 W/m2

During the Day Time:

The Surface temperature of the developed Super Cool Materials was in average 6 C lower than the ambient one while during the peak ambient temperature the cooling of the SCM was 3-4 C.

During the Night Time:

The Surface temperature of the SCM was almost 10 C lower than the ambient one.

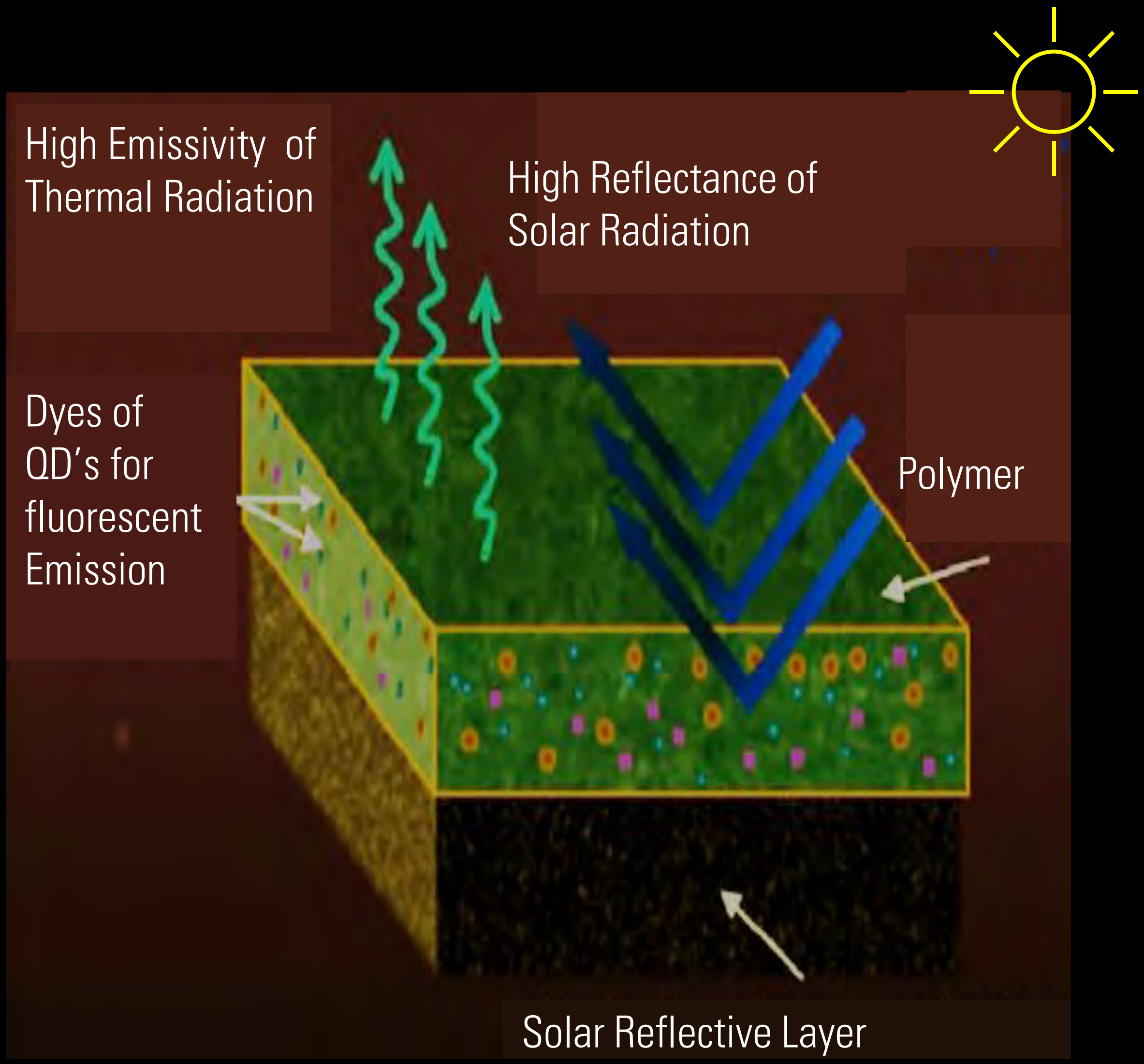


Figure idea :Colored radiative cooling coatings using phosphor dyes : J. Xu, R. Wan, W. Xu, Z. Ma, X. Cheng, R. Yang, X. Yin

Colored Radiative Coolers based on the use of fluorescent materials have been developed and tested.

Materials were designed in order to present:

- High Reflectance to Solar Radiation
- High Emissivity in the Atmospheric window, and
- High radiative losses because of the fluorescent emission

The developed colored radiative coolers were composed by two or three specific layers:

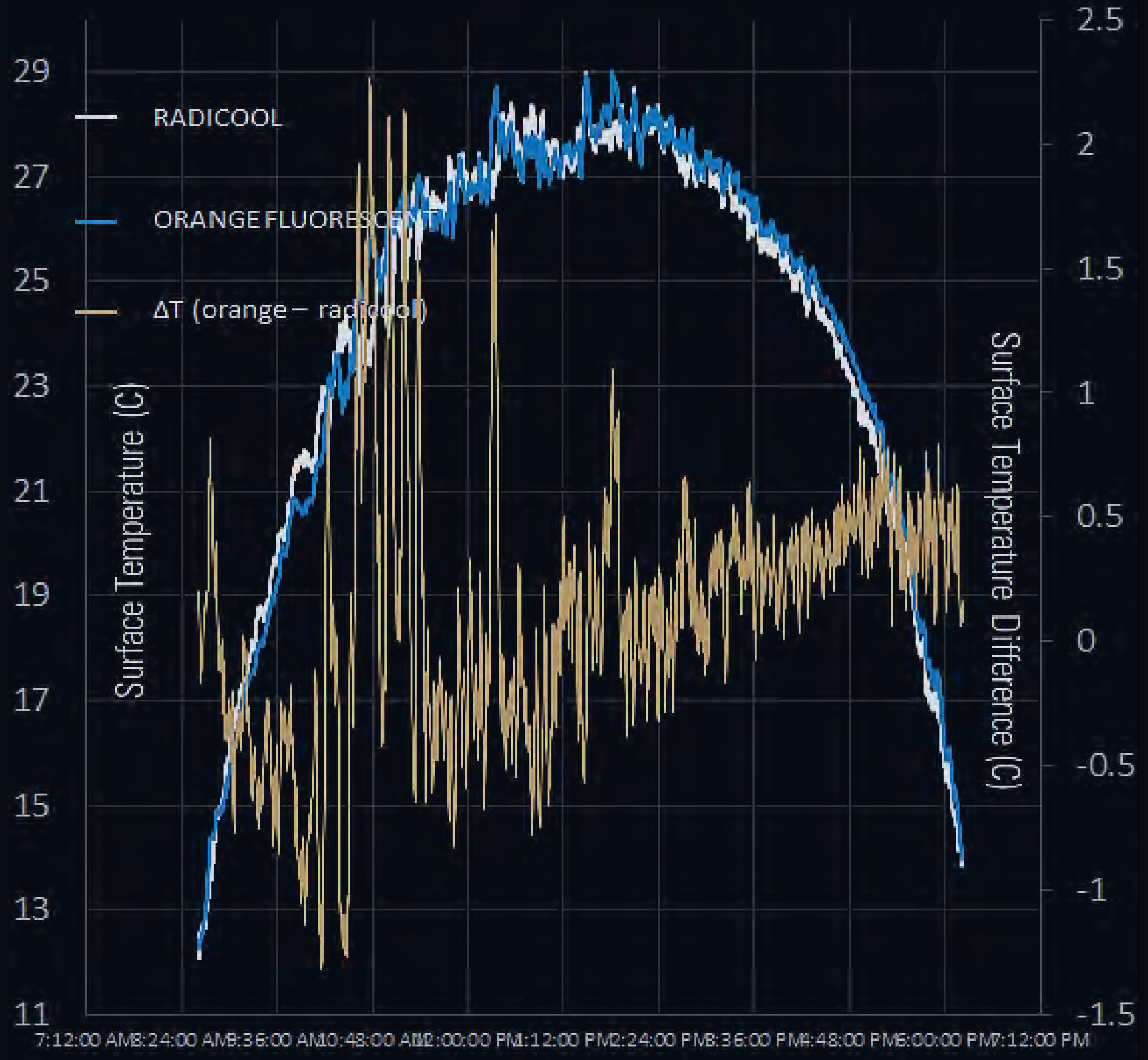
- A reflective layer, and
- A high emissivity and/or a high PLQY layer on the top to provide fluorescent emission at various colors and also high emissivity in the atmospheric window

All developed materials have been tested extensively during the summer of 2023 in Alice Springs, in the Australian desert.

Climatic Conditions

Maximum Daytime Ambient Temperature : 27.5 C
Maximum Daytime Rel Humidity : 50 %
Minimum Daytime Rel Humidity : 20 %
Average Daytime Wind Speed : 1.4 m/sec
Maximum Daytime Wind Speed : 7.2 m/sec

Maximum Solar Radiation : 750 W/m2
Average Daytime Long Wave Radiation : 300 W/m2



25/5/2023 – Alice Springs- Orange Fluorescent SC Material

Max Amb. Temp : 27.4 C

Max SR : 740 W/m2

RH (noon) : 20 %,

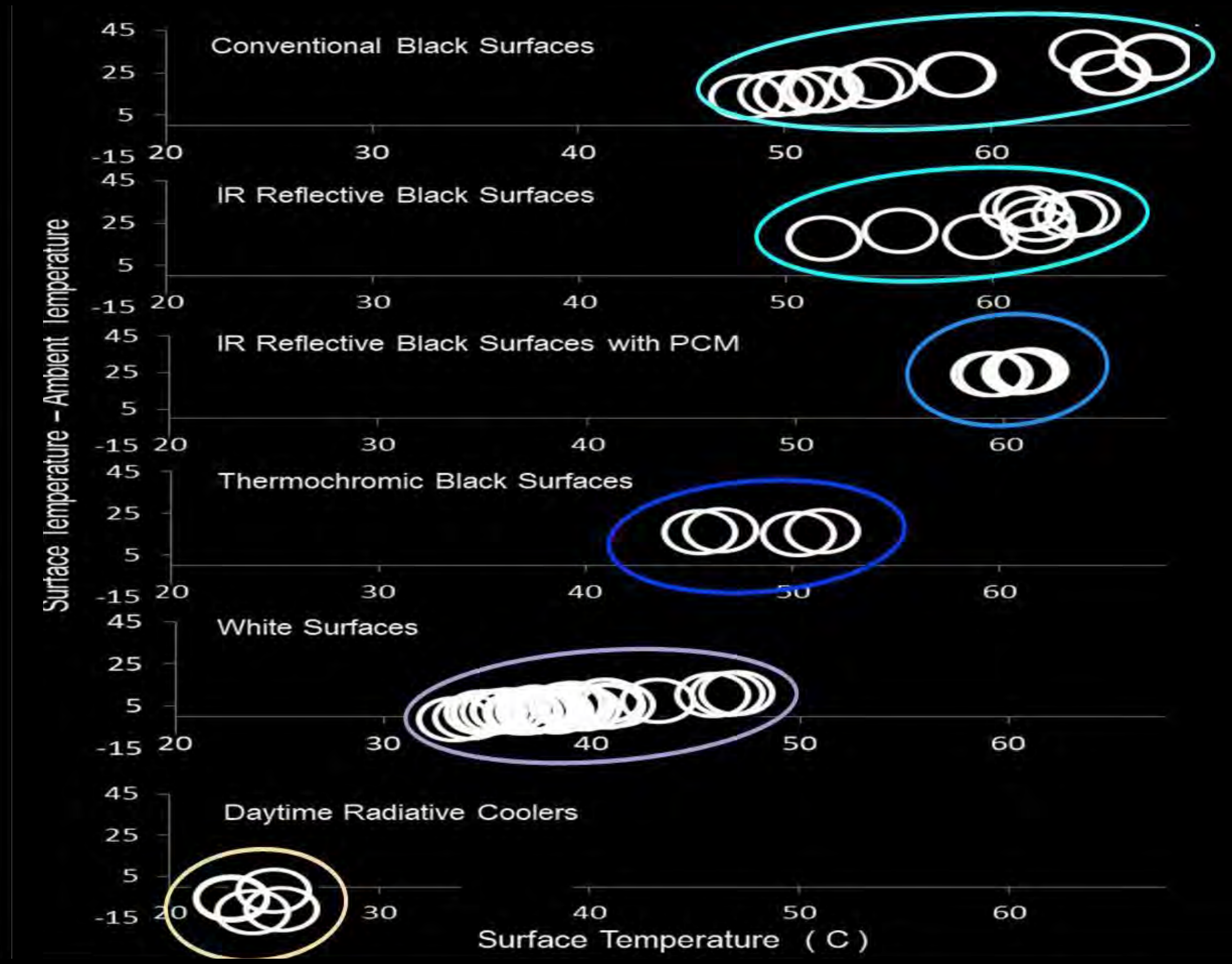
Max Atm Rad : 370 W/m2

Comparison of the Orange Colored SCM against the White SCM

During the day time the average temperature of the white SCM was 24 C

while of the Orange SCM was 24.1 C

The orange Super Cool material exhibited during the day time period up to 1.5 C sub-ambient temperature.

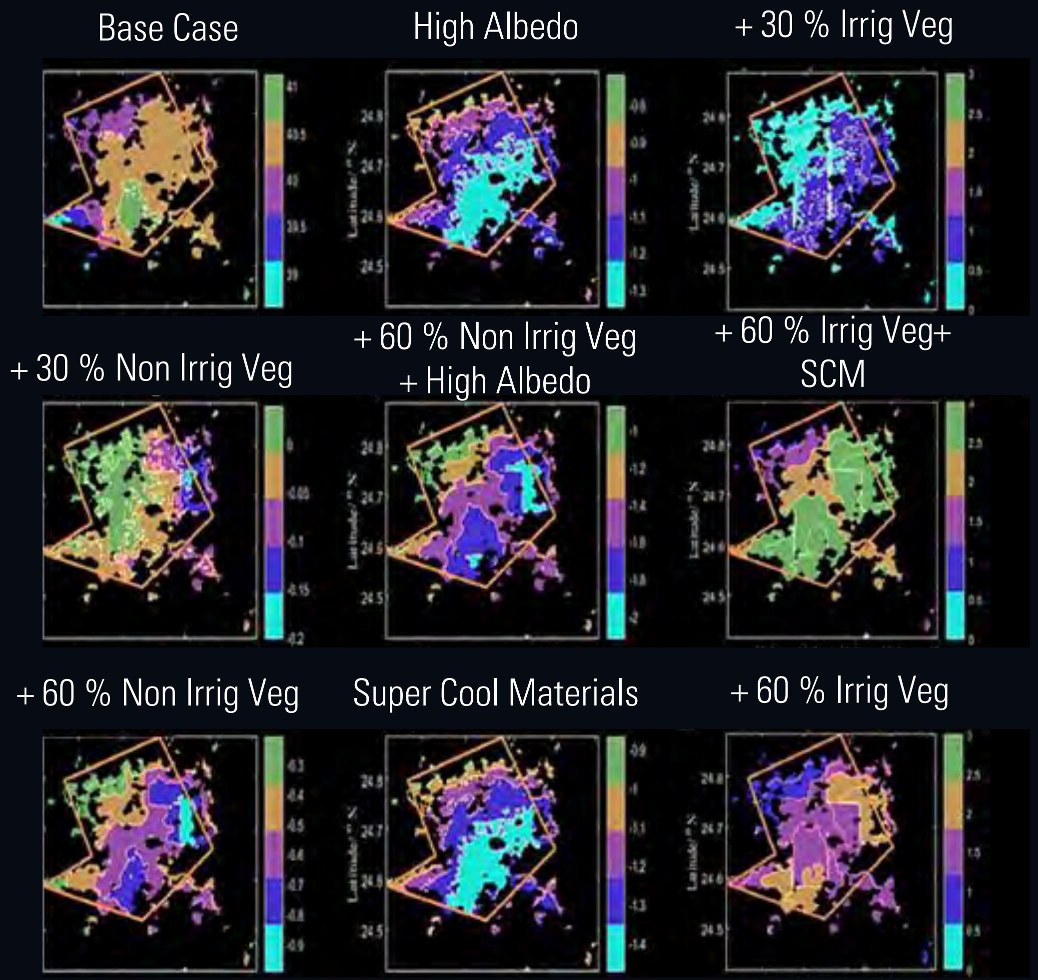


Comparative outdoor assessment of the main types of coatings for the built environment carried out under similar climatic conditions demonstrated the important progress in terms of cooling mitigation potential.

It is found that Super Cool Materials present almost 10-15 C lower surface temperature than the conventional reflecting white coatings.

In parallel, the use of Super Cool Materials can decrease the surface temperature of dark color cities up to 30 C

The developed Super Cool Materials have been considered as the primary heat mitigation strategy to decrease the ambient temperature and reduce the energy consumption of buildings in numerous cities.



Results from the Heat Mitigation Study in Riyadh, KSA

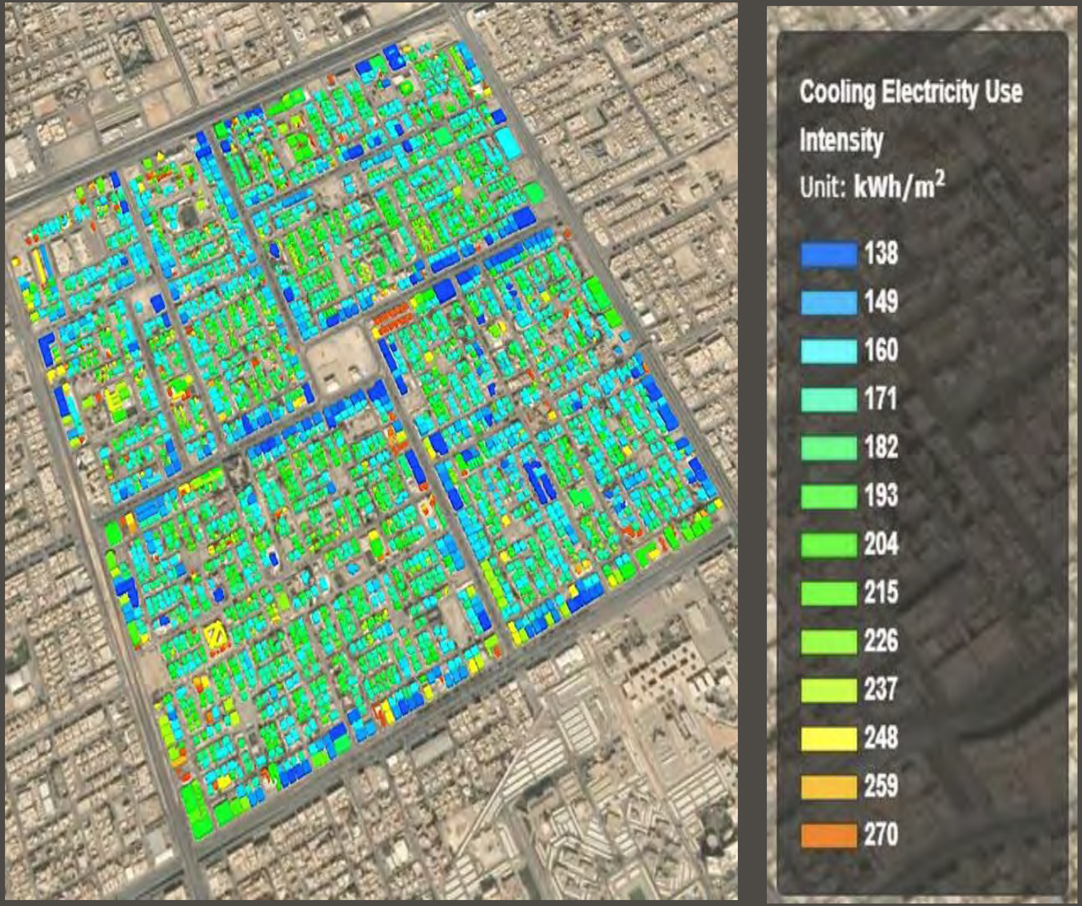
- Use of white super cool materials in the roofs of the city, can reduce the peak daytime summer temperature up to 2.8 C

- Combined use of white SCM on the roof of buildings, with well irrigated greenery, can reduce the peak day summer ambient temperature up to 4.6 C

- Increase of the albedo in the city by 0.4 can reduce the peak daytime ambient temperature up to 1.5 C.

S. Haddad et al : **Quantifying the Energy Impact of Heat Mitigation Technologies at the Urban Scale,** Nature-Cities, 2024

The combined use of white super cool materials on the roofs of buildings with well irrigated additional greenery provides serious energy benefits during the summer period and decreases considerably the cooling demand of buildings. .



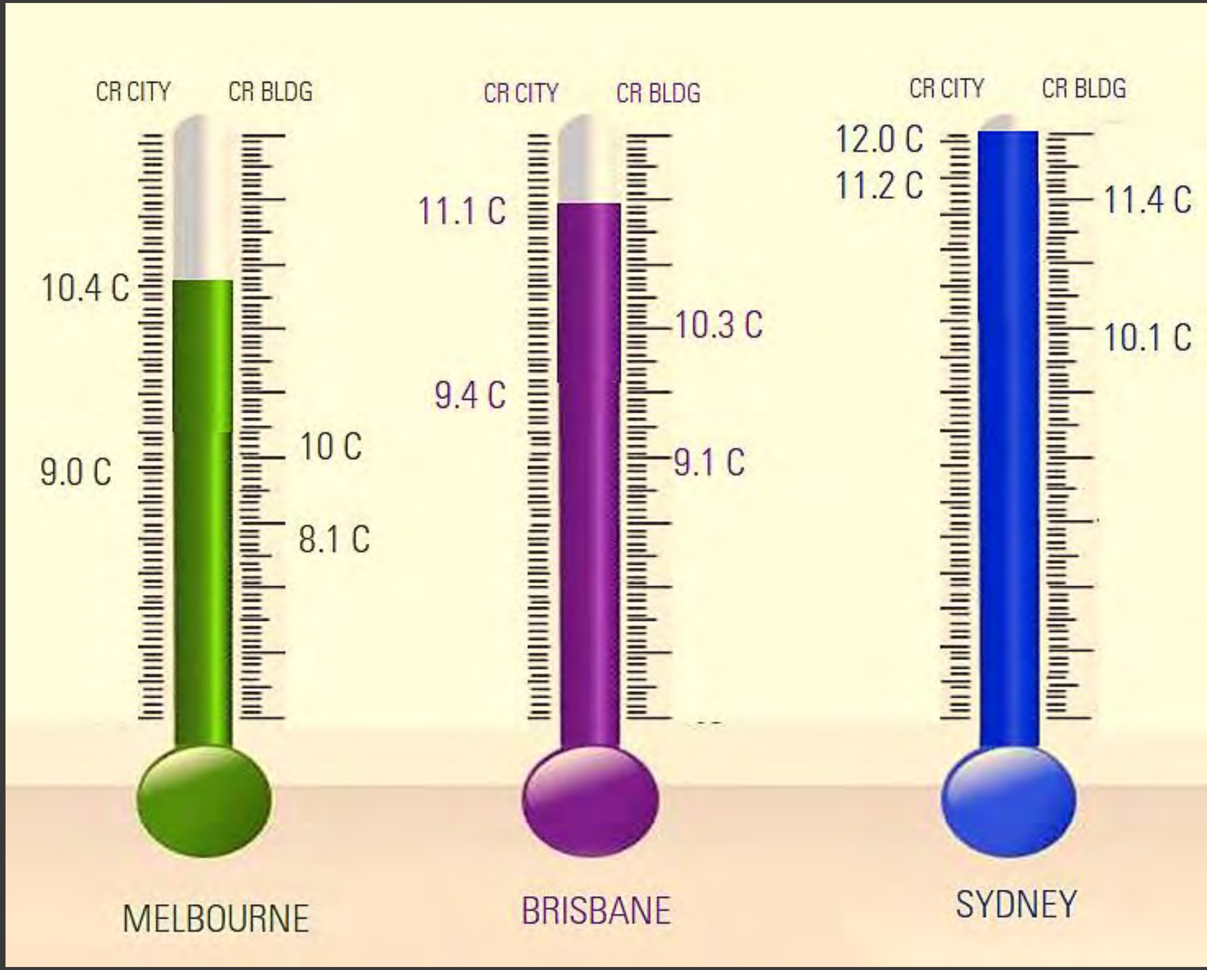
Results from the Heat Mitigation Study in Riyadh, KSA

- Use of white super cool materials in the roofs of the city, can reduce the cooling demand of buildings up to 10 %

- Combined use of white SCM on the roof of buildings, with well irrigated greenery, can reduce the cooling demand of buildings up to 17 %.

- Combined use of white SCM on the roof of buildings, with well irrigated greenery and energy adaptation measures can reduce the cooling demand of buildings up to 35 %.

S. Haddad et al : **Quantifying the Energy Impact of Heat Mitigation Technologies at the Urban Scale,** Nature-Cities, 2024



A study has been performed by the Department of Industry in Australia to assess the impact of cool roofs in the major Australian cities has concluded that:

Main Results of the Study

The implementation of cool roofs in low income houses in Australia, not insulated buildings can decrease the peak indoor summer temperature up to 12 C.

Cool Roofs can improve tremendously thermal comfort during the warm period of the year and decrease substantially heat related mortality and morbidity

S. Garshasbi, Jie Feng, Riccardo Paolini, Jean Jonathan Duverge ,Carlos Bartesaghi-Koc, Samaneh Arasteh, Ansar Khan, M. Santamouris : On the energy impact of cool roofs in Australia, Energy and Buildings, Volume 278, 1 January 2023, 112577


"Somehow we need to monetise this - and quickly"

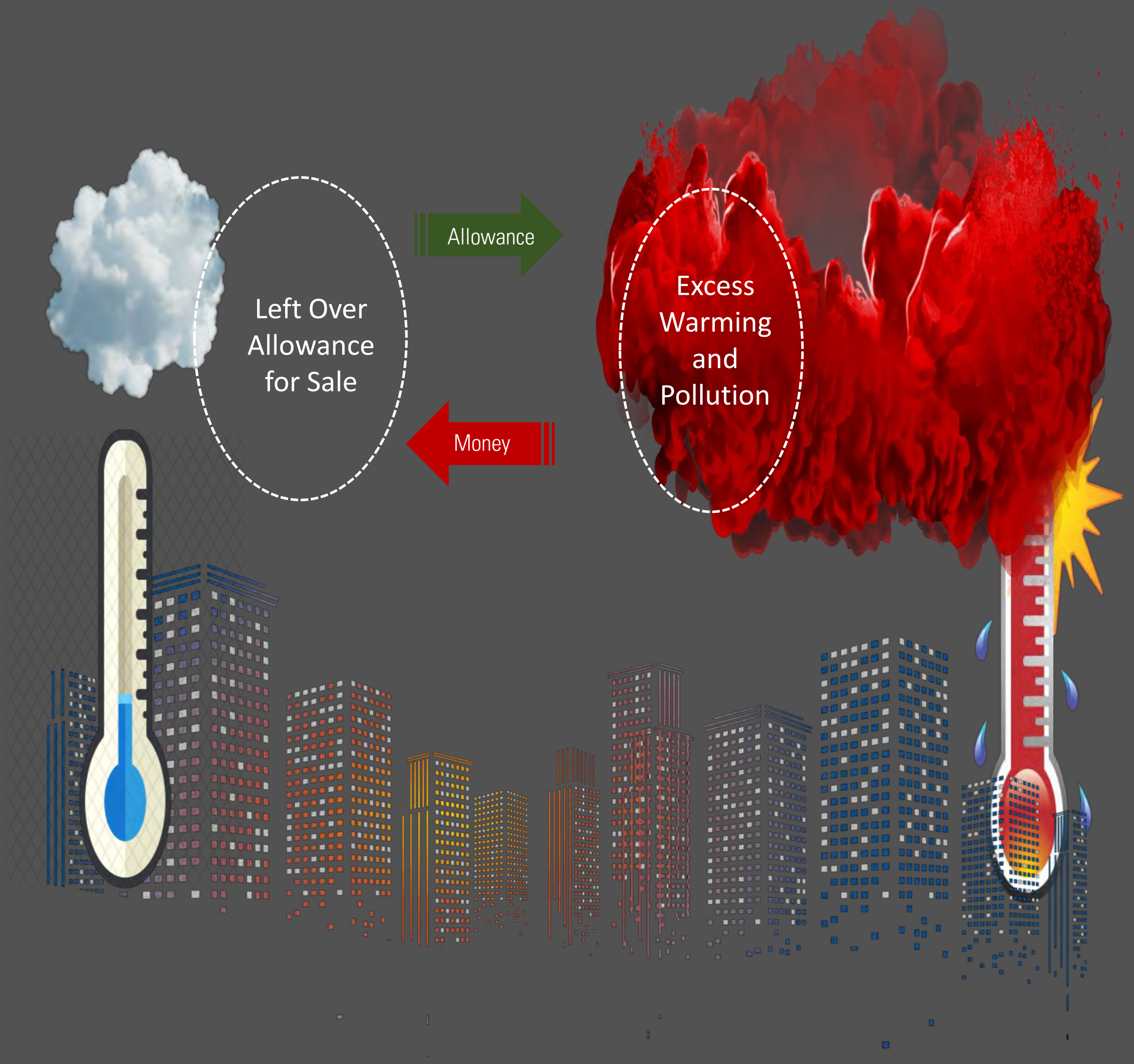
Establishment of Urban Warming Markets

Setting as a goal a minimum urban overheating and pollution involves limiting the strength of warming and polluting sources and increasing the strength of urban heat sinks to balance the urban heat budget.

Achieving a Zero Urban Thermal and Pollution budget requires to:

Change the way we design, build and operate urban buildings, spaces and infrastructures and transition to less warming and polluting patterns and policies

Put a value on the urban mitigation and adaptation capital that limits the strength of local climate change and environmental quality



Putting a Price on Urban Warming

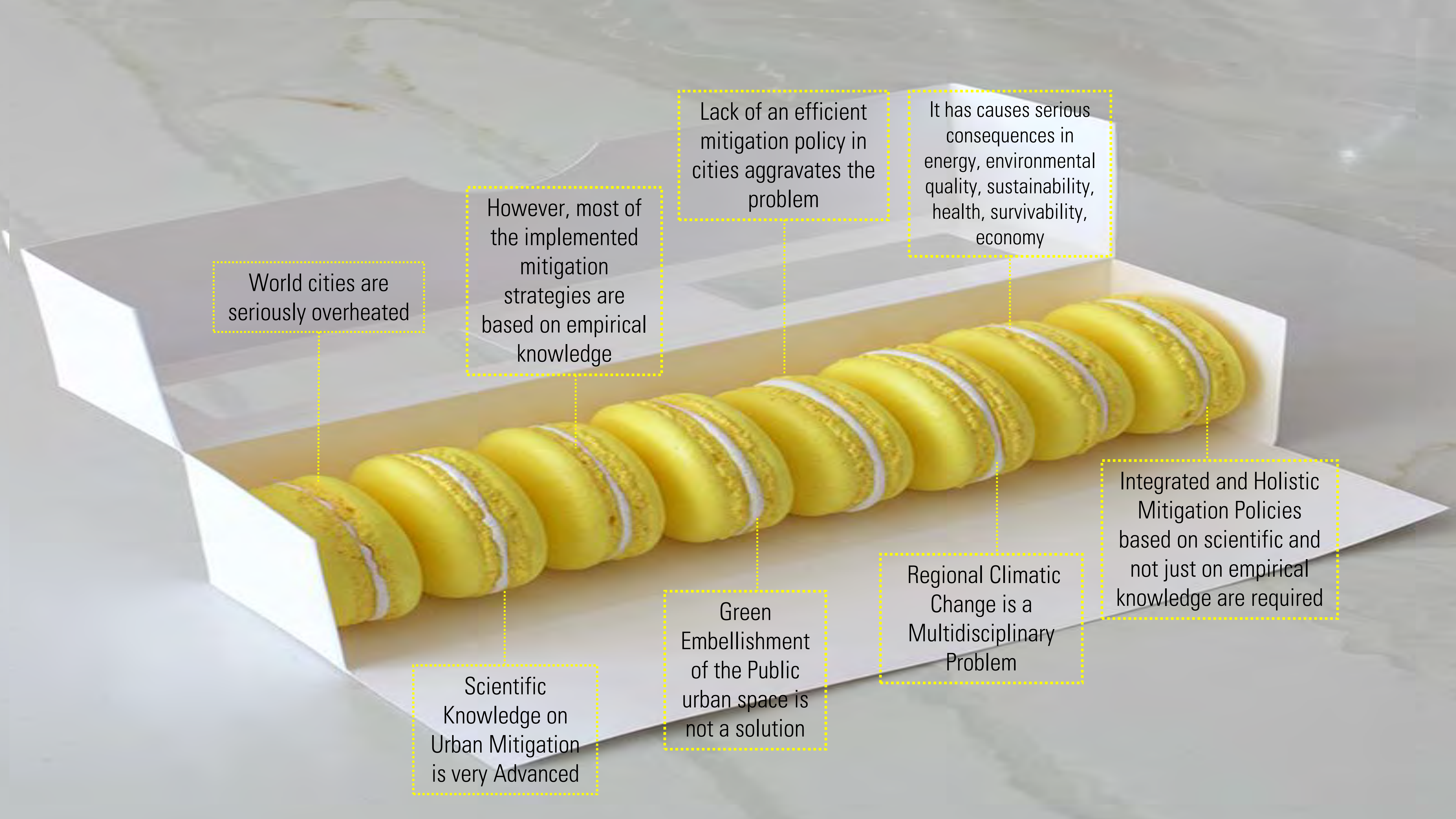
The magnitude of overheating and pollution caused by selected major urban activities has to be assessed and controlled.

Liable entities exceeding the threshold and causing urban warming must pay a price for every warming or pollution unit, shortfall cost, or to surrender the appropriate number of allocated units.

Boosting Sustainable Urban Investments

To accelerate urban cooling and finance urban heat mitigation and adaptation it is critical to value urban overheating with liquidity.

The development of a voluntary Urban Warming Market could bring urban mitigation and adaptation investments sooner to the market and make them more affordable.



World cities are seriously overheated
However, most of the implemented mitigation strategies are based on empirical knowledge
Lack of an efficient mitigation policy in cities aggravates the problem
It has causes serious consequences in energy, environmental quality, sustainability, health, survivability, economy
Integrated and Holistic Mitigation Policies based on scientific and not just on empirical knowledge are required
Regional Climatic Change is a Multidisciplinary Problem
Green Embellishment of the Public urban space is not a solution
Scientific Knowledge on Urban Mitigation is very Advanced